## THE U.S. SEMICONDUCTOR MANUFACTURING EQUIPMENT INDUSTRY

Like the U.S. semiconductor industry it serves, the U.S. semiconductor manufacturing equipment (SME) industry has been losing market share to its Japanese counterpart. Although producers in the United States still dominate in many areas of manufacturing, several panels of experts have sounded alarms regarding future technological trends.

Industry experts estimate total 1985 worldwide sales of semiconductor manufacturing equipment to have been in the range of $6.0 billion to $6.5 billion.19/ In 1986, sales dropped to roughly $5.0 billion as a result of the worldwide semiconductor recession. This decline was a substantial reversal; sales of semiconductor manufacturing equipment had been growing at an annual rate of over 25 percent since 1979.20/

In 1986, U.S. firms sold roughly $2.8 billion of the world total, while Japanese SME firms sold $1.7 billion. The U.S. share of worldwide SME sales--about 55 percent--corresponds roughly to the U.S. share of the semiconductor market and has been declining.21/

In 1986, equipment purchases by Japanese and U.S. manufacturers of semiconductors were each in the range of $2.2 billion. U.S. capital-affiliated companies produced over 80 percent of the equipment bought in the U.S. market, but only 30 percent of that bought in the Japanese market. However, the proportions were more than reversed for Japanese producers: they manufactured 60 percent of the equipment purchased in Japan but only 11 percent of U.S. purchases. In other countries, U.S. firms had almost 50 percent of the market, while Japanese firms had less than 25 percent.

---

19. The estimates are largely taken from Jerry Hutcheson, "Front-End Wafer Fab Equipment Marketing Forecast," in Semiconductor Materials and Equipment Institute, *Forecast: The Business Outlook*, pp. 198-223.

20. Extrapolated from Department of Commerce, *A Competitive Assessment of the U.S. Semiconductor Manufacturing Equipment Industry* (March 1985), p. 31.

21. Department of Defense, *Report of the Defense Science Board Task Force on Semiconductor Dependency*, p. 5.

## Structure of the U.S. Semiconductor Manufacturing Equipment Industry

The large size of the U.S. semiconductor industry allows producers of manufacturing equipment to specialize; many firms produce equipment for only one specific step in the highly exacting process of manufacturing semiconductors (described in Appendix B). About 700 companies produce manufacturing equipment, while many fewer companies produce the semiconductors themselves.22/ A few SME firms have substantial sales, but most have sales under $20 million. Most firms also have only one or a handful of products. As a result of this specialization, the top 14 companies account for only 55 percent of sales.23/

It is easy to enter the industry. Engineers from established companies regularly tap into venture capital funds to do so. Furthermore, the rapid growth in the complexity of semiconductor devices and the equipment that makes them has provided many openings for new entrants.

The Japanese SME industry, with about 500 firms, has a similar structure, although it is somewhat more concentrated than the U.S. SME industry--the top 11 SME firms in Japan account for 72 percent of sales.24/ There have been some major Japanese successes in this area, most notably the advances made by Nikon and Canon in lithography.

## The State of U.S. Manufacturing Technology

Measuring the technological competitiveness of an industry (particularly one composed of many small, specialized producers) is far

---

22. The Semiconductor Industry Association (SIA), the U.S. trade association, has 60 members but represents only part of the industry. One study suggested that 113 new semiconductor firms were started since 1977. Of course, many may have failed in the recent industry downturn. See Michael Malone, "America's New-Wave Chip Firms," *Wall Street Journal*, May 27, 1987.

23. Department of Commerce, *A Competitive Assessment*, p. 52.

24. Ibid., p. 53.

from exact. Several recent studies, however, have suggested that the Japanese semiconductor manufacturing technology is superior to U.S. technology and is advancing rapidly. The most detailed of these studies was done by a panel of experts assembled by the National Research Council (NRC), the operating arm of the National Academy of Sciences.25/ According to the NRC panel, the United States held the lead in three established areas of semiconductor manufacturing technology, but lost control of one major area (lithography) in the last year. Of greatest concern to the panel, however, were seven emerging technological areas in which Japanese firms were believed to be leading. Thus, while the United States is currently ahead, the NRC panel suggested that Japan seems to be gaining in these areas.

Some people have argued that the quality of Japanese manufacturing equipment is not necessarily the cause of either the greater competitiveness of Japanese semiconductor producers or the current weakness in U.S. semiconductor manufacturing. U.S. makers of semiconductors have access to most of the same manufacturing equipment as the Japanese firms, although some advanced testing equipment is not yet available in the United States. Although the Japanese investment rate has been higher than that of U.S. semiconductor producers, between 1980 and 1986 producers in both countries spent roughly the same amount on capital improvements.26/ Furthermore, U.S. producers probably have about the same number of new machines as do Japanese producers, even if the latter have a greater percentage of their capital stock invested in more modern technology.

The introduction by Japanese semiconductor producers of newer and more modern equipment, however, can quickly turn into a technological advantage. For example, one measure of the technical sophistication of equipment is the diameter of wafer used by a fabrica-

25. National Research Council, Commission on Engineering and Technical Systems, Panel on Materials Science, *Advanced Processing of Electronic Materials in the United States and Japan* (Washington, D.C.: National Academy Press, 1986).

26. Integrated Circuit Engineering Corporation, Scottsdale, Arizona.

tion line. Semiconductor manufacturing equipment typically works most economically when using the largest wafer available.27/ Most new wafer fabrication lines are 6-inch (150-millimeter) lines. Fabrication lines using 4-inch wafers are at least two generations behind--in the United States, three-quarters of all wafer fabrication lines are 4 inches or less. By contrast, in Japan, only 40 percent are that size.28/

Japanese companies also seem to make better use of the equipment they have than do U.S. companies. This belief is held by many equipment manufacturers and semiconductor producers in the United States. Japanese companies often run their equipment three shifts a day: for two shifts the equipment is used in production; for the third shift, it is recalibrated and serviced. Comparable U.S. firms reportedly run similar machines until they need maintenance. Japanese semiconductor firms often add custom features to their machines and improve the materials-handling capabilities of the manufacturing equipment, presumably to fit into automated manufacturing strategies. Although U.S. semiconductor companies have a long history of making improvements in the capital equipment that is purchased from SME producers, they are nonetheless perceived by many people as lagging Japanese companies.29/

In the semiconductor industry, equipment use can affect output quantities very easily by increasing yields. Japanese manufacturers typically have been concerned with the acceptance rate of their

27. Wafers with a larger surface area can accommodate a larger number of integrated circuits, which generally will lower the production costs. Some of the advantage of a larger surface area, however, is lessened by the concomitantly larger perimeter, which is where defects are likely to occur.

28. Beedle, "Semiconductor Industry Statistics," pp. 31-53.

29. See Eric Von Hippel, "The Dominant Role of the User in Semiconductor and Electronic Subassembly Process Innovation," *IEEE Transactions in Engineering Management* (May 24, 1977), pp. 60-71. For a more recent discussion, see Bruce Guile, "Investigation of a Transaction-Cost Approach to Market Failures in the Development and Diffusion of Manufacturing Technologies," presented to the Association for Public Policy Analysis and Management, Austin, Texas, October 1986.

output.30/ Their yields are therefore higher than those of their U.S. competitors, particularly for DRAMs. Higher yields lower the costs of products. Thus Japan's advantage in production technique may be more important than any advantage in production equipment.

Finally, Japanese firms are the leading providers of materials with which semiconductor devices are made. Six of the top ten semiconductor materials firms in 1986 were Japanese.31/ Japanese firms provided 92 percent of ceramic packages, 80 percent of the frames on which the actual semiconductor dies are mounted, and about 75 percent of the molding compound. Almost half the silicon wafers came from Japan.32/

## CONCLUSIONS

The U.S. semiconductor industry's technological and market dominance is being threatened, partly by foreign competition, but more likely by internal weaknesses. Although Japanese producers now dominate the commercial DRAM market, their success has not yet led to large-scale penetration of other semiconductor markets traditionally held by U.S. companies; nor have they eliminated the production of DRAMs by U.S. captive firms.

Two trends, however, foreshadow problems for the U.S. semiconductor industry. First, the loss of market share by U.S. firms is likely to continue because other countries--like Korea--will probably begin large-scale production of semiconductors. Second, and more important, there is clear evidence of a weakness in manu- facturing techniques and possibly in equipment technology compared with

30. William Finan and Annette LaMond, "Sustaining U.S. Competitiveness in Microelectronics: The Challenge to U.S. Policy," in Paul Krugman, ed., *Strategic Trade Policy and the New International Economics* (Cambridge, Mass.: MIT Press, 1986), p. 156.

31. "IC Equipment Makers Get Down to Business," *Electronic Business*, May 1, 1987, p. 84.

32. Daniel Rose, "Semiconductor Material Trends: Major Issues, Fab and Packaging Materials," in Semiconductor Equipment and Materials Institute, *Forecast: The Business Outlook*, pp. 31-53.

76-700 0 - 87 - 2

those used by Japanese producers. This weakness could easily translate into significant cost (hence price) advantages for Japanese semiconductor manufacturers. Other studies have provided analyses similar to this report, downplaying the importance of the DRAM market and emphasizing the weakness in U.S. semiconductor manufacturing practice.33/

On the other hand, many observers, both within and outside the semiconductor industry, have been more concerned about the loss of the merchant DRAM market and the slow pace of advances in equipment technology. A report of the Defense Science Board task force on semiconductors reflects this view. The report concluded that "...the current position of the overall U.S. merchant industry is...very tenuous in terms of present manufacturing capability."34/ The National Research Council report on manufacturing technology also presented a negative forecast. Yet the factors that encouraged Japanese firms to enter and then take over the DRAM market (for example, their mass-manufacturing skills) have not yet been shown to be applicable to other semiconductor devices.35/

---

33. McKinsey & Co., a consulting firm, often takes this position. See Bob Neely and Mike Nevens, McKinsey & Co., "Politics Won't Cure the U.S. Chip Industry Woes," *Electronic Business*, November 15, 1986.

34. Department of Defense, *Report of the Defense Science Board Task Force on Defense Semiconductor Dependency*, p. 13.

35. National Defense University, Institute for National Strategic Studies, Mobilization Concepts Development Center, "Integrated Circuits: A Case Study of a Potential Foreign Source Dependency" (March 1987), unpublished mimeo.

# CHAPTER III

# THE SEMICONDUCTOR INDUSTRY AND THE PUBLIC INTEREST

Beyond the prospects for the future competitiveness of the U.S. semiconductor industry lies the more important issue of whether the competitiveness of that industry is an appropriate matter for public concern. Many of Sematech's proponents perceive the program as a response to a growing competitive disadvantage in international semiconductor trade. The benefits of Sematech, according to this view, are the output and employment associated with current and future semiconductor production that would otherwise be lost.

But while exceptions exist, the basic tenets of U.S. economic policy hold that shifts in the composition of the economy do not generally require government intervention. The rise and fall of individual industries, and the concomitant adjustments they require, may be caused by factors such as changing consumer tastes or technological advancement, as well as competition from imports. Thus, whatever the cause, the public policy role is typically limited to programs that help workers or communities adjust to economic change.

The roots of this policy of noninterference are found in economic theory. In the specific case of trade, if domestic production is displaced by imports, then the resources devoted to production of domestic goods will be freed for alternative uses. Through this process of displacement and adjustment, free international trade allows nations to specialize in producing goods and services according to their "comparative advantage" as evidenced by markets. This process, it is argued, ultimately will align the goods nations produce with their endowment of resources.

Yet this view of international trade has been challenged on several scores. Most notably, a growing majority of world trade is intra-industry trade--that is, trade in which nations with comparable levels of resources simultaneously import and export the same good. Thus, many analysts find it increasingly difficult to define comparative advantages among nations based on resource endowments, and often ascribe trade patterns to more broadly defined societal assets such as education, technology, culture, and government policies.1/

An exception to the principle of noninterference in the industry-level workings of the economy has traditionally been condoned when government intervention is needed to correct for so-called "market failures." Such failures occur, for example, when private economic actors correctly respond to market signals but the outcome is less than optimal from a societal perspective. A firm, for example, might produce and invest less than would be best for the economy as a whole if the benefits of its investments were usurped by other firms without compensation. Or, it might overproduce and overinvest if it were not required to pay the full social costs of its production, such as the costs of environmental degradation.

Given the traditional commitment to a policy of noninterference, the burden of proof is on proponents of government intervention--like Sematech's proponents--to demonstrate that market failures exist and warrant targeted economic policies. In essence, proponents must identify some type of public benefit associated with semiconductor production that accrues to the national economy, not just to individual semiconductor firms. Identifying these public benefits is somewhat subjective, but at least three types can be advanced: national security, research and development (R&D) results that benefit (or "spill over" to) the entire semiconductor industry, and spillovers to the economy as a whole.

## NATIONAL SECURITY

The electronic content of U.S. weapons systems has been rising continuously throughout the last few decades. Computers and software accounted for about 2 percent of the cost of an F-4 Phantom in the 1960s, but for 25 percent of the cost of the next generation of military aircraft, the F-15. For the current generation, the F-18,

1. For a short summary of intra-industry trade theory, see Paul Krugman, "New Theories of Trade Among Industrial Countries, " *American Economic Review* (May 1983), pp. 343-347. See also, Henry Kierzkowski, ed., *Monopolistic Competition and International Trade* (Oxford: Clarendon Press, 1984).

between 40 percent and 50 percent of all system costs are for electronic components.2/ In essence, U.S. military strategy has come to rely on electronic systems as the backbone of the U.S. strategy of having relatively few, but very sophisticated, weapons.

The Department of Defense's (DoD's) dependence on the U.S. electronics sector for its weapons systems is manifest in two interrelated ways. First, the DoD buys sophisticated electronics from domestic producers and wants to maintain a secure supply. Second, it relies on the industry to maintain the expertise needed to deliver state-of-the-art weapons systems. The semiconductor task force of the Defense Science Board (DSB), set up in 1986 to examine the impact of military dependency on foreign sources of semiconductors, reflected a concern about the second source of dependency as much as the first.

If the issue centered on maintaining a supply of semiconductors and eliminating constraints on foreign policy posed by dependence on foreign suppliers, the DoD could build semiconductor manufacturing plants dedicated solely to production for defense needs, or it could stockpile semiconductors (the military demand for imported semiconductors is only 0.1 percent of world output).3/ But these solutions would be more costly than Sematech.

More important, these solutions would ignore the interactions between maintaining a secure domestic supply of semiconductors and the ability of domestic suppliers to maintain technological expertise. Weapons contractors depend on a healthy commercial industry for such expertise. If the U.S. semiconductor industry were to deteriorate substantially, it is argued, U.S. firms would no longer be in a position to produce state-of-the-art or even current-generation chips for military uses. The Defense Department would lose the "know-how" embodied in the industry, and would find it more difficult to apply technology to defense needs. Thus, the ability to produce defense systems may deteriorate.

2. Dr. Arvid Larson, Statement on the Department of Defense FY 1987 Budget for R&D before the House Appropriations Committee, Subcommittee on Defense, April 29, 1986.

3. Calculated from Department of Defense, Defense Science Board, *Report of the Defense Science Board Task Force on Defense Semiconductor Dependency* (February 1987), pp. 4 and 63.

The national security argument for Sematech, therefore, appears to rest more on concerns over losing a domestic technological base. Until now the Defense Department has assumed that the U.S. technological base was at the leading edge of semiconductor technology. The problem, for the military, was how to absorb and use the products generated from this base. The ability of the domestic semiconductor industry to compete with foreign producers allows the military to have access to state-of-the-art technology. For example, DoD was moved to oppose Fujitsu's bid to takeover Fairchild, probably not because of concern over security of supply, but because of concern over maintaining a domestic technological base. The military concern, therefore, is that this technological base can no longer be taken for granted.

## SPILLOVERS WITHIN THE SEMICONDUCTOR INDUSTRY

One of the traditional arguments for public support of R&D is that the market, left to its own devices, will not invest in the "right" amount of R&D and will not make these investments in the "right" places. In research areas where it is hard for individual firms to capture all the benefits, such as basic and applied research, companies will have less incentive to invest than the good of society might suggest.4/ Thus markets may fail to deliver the right amount or composition of R&D.5/

The available evidence, at least among producers of semiconductor manufacturing equipment (SME), appears to conform to these theoretical expectations. The "know-how" that is developed by these producers can easily be transferred within the industry. Thus, unable to capture the full benefits of their research, firms spend less effort developing easily replicated improvements in technology. Foreign (Japanese) producers do not appear to succumb to this problem, partly because of efforts to perform this research on a collective basis.

---

4. In other areas where there is substantial competition but firms are able to capture the bulk of the benefits (through product differentiation, for example), then firms might invest more than is socially necessary.

5. See Congressional Budget Office, *Federal Support for R&D and Innovation* (April 1984), pp. 10-17.

The focus of U.S. producers of semiconductor manufacturing equipment on short-term R&D gains has been suggested as a reason why they have fallen behind Japanese manufacturers, who have invested more heavily in long-term R&D (see Chapter II). In the National Research Council (NRC) report comparing U.S. and Japanese semiconductor manufacturing technology, the NRC panel found that "Japan's semiconductor industry is made up of at least ten entities that pursue long-range research and development on a scale matched by only a few U.S. companies."6/ The panel also noted that the Japanese industry and government are committed to pursuing R&D projects with lead times of 10 years. By contrast, most SME producers in the United States are small firms and cannot afford to wait 10 years for a return on their R&D investment, especially if a large share of the market will be captured by imitators, who copy the innovative product or process without compensating the original innovator.

Imitators that capture large parts or even the bulk of the market are a problem within the semiconductor industry itself. One study of semiconductor market share found that, depending on the type of device, innovators might not fare well at all. For evolutionary devices (such as the first 64K DRAM, which incrementally improved upon 16K DRAMs), the innovator of a new device lost the lead in market share in roughly two-thirds of the cases. For radically new devices, on the other hand, the innovator held the lead in market share in three-quarters of the cases.7/ This result suggests a pattern of overinvestment in radically new devices to hold market share and underinvestment in the commonplace improvements that allow for evolution of devices and manufacturing processes. The strengths and weaknesses (strong in design and weak in manufacturing technology) found among U.S. semiconductor firms suggest exactly this pattern.

---

6. National Research Council, Commission on Engineering and Technical Systems, Panel on Materials Science, *Advanced Processing of Electronic Materials in the United States and Japan* (Washington, D.C.:National Academy Press, 1986), p. 32.

7. Francis C. Spital, "Gaining Market Share Advantage in the Semiconductor Industry by Lead Time in Innovation," in Richard S. Rosenbloom, ed., *Research on Technological Innovation, Management and Policy* (Greenwich, Conn.: JAP Press, 1983), pp. 147-173.

Sematech would concentrate on the manufacturing process--the area in which U.S. semiconductor producers devote the smallest share of their R&D effort. Industry sources suggest that U.S. producers spend no more than 10 percent to 15 percent of their R&D dollar on manufacturing technology. In the past, U.S. producers of semiconductors have devoted a great deal of resources to designing a product and to the initial manufacturing effort. Evidence suggests that once the product was fully launched, the resources were removed and yields stopped growing.8/ By focusing on manufacturing R&D, Sematech may alleviate the stagnation that is occurring after a product has been successfully introduced.

## SPILLOVERS TO THE ECONOMY

Because the Sematech consortium would concentrate on manufacturing R&D, its developments should lower the costs of all semiconductor devices, not just those produced by Sematech members. Moreover, since semiconductors now have so many applications, these cost reductions should spread throughout the economy. If Sematech achieves its goals, the nation would benefit both from the better quality and lower cost of semiconductors the industry produces and from the incorporation of these devices in the products of other industries. An additional spillover benefit would be the development of the scientific and engineering personnel working on these projects.

Two analyses have suggested that the social benefits derived from recent technological advances are vastly larger than the private benefits to such activities and give credence to the traditional argument that R&D in technology promotes greater societal returns than just those that can be captured by private recipients. Even though these analyses measure the benefits of innovations in the computer industry, they are relevant here because semiconductors are

8. In some sense, the behavior of semiconductor producers is consistent with the "satisfying" hypothesis--that is, once they hit a cost and productivity target, they cease trying to make further improvements. See Philip Webre, "Technological Progress and Productivity Growth in the U.S. Semiconductor Industry" (Ph.D. Dissertation, American University, 1983), pp. 139-140.

related to computers, and advances in computers are largely associated with advances in semiconductors.9/

One study found that the benefits of lower costs of computers in the financial services sector were larger than the computer expenditures of that sector by 1.5 to 2.0 orders of magnitude.10/ This result was derived by measuring the willingness of the adopting industry (financial services) to pay for the technological advances of the supplying industry (computers).

The other study found that the social rate of return on computer R&D varies between 50 percent and 70 percent, depending on assumptions of world market share and market structure. The rate of return to society is calculated based on the relationship between public and private investments in computer R&D, and the benefits of lower information-processing costs to consumers. Comparing the private and public rates of return, using the same assumptions, indicates that private rates of return are no more than roughly half as large as estimated public returns.11/ This differential implies that, in retrospect, the massive federal investment in support of computer R&D following World War II was indeed justified by the spillover benefits. This differential in the private and social benefits is consistent with other studies of industrial R&D investments, which find that, on average, the social rate of return is roughly twice the private rate.12/

This argument, however, is difficult to apply to any individual policy or R&D program. Even if, on average, the social rate of return

9. Because semiconductors have other uses, these analyses may understate the full societal impact of semiconductor devices.

10. Timothy Bresnahan, "Measuring the Spillovers from Technical Advance: Mainframe Computers in Financial Services," *American Economic Review* (September 1986), p. 753.

11. In no case is the private rate of return larger than 55 percent of the equivalent social rate of return. Kenneth Flamm, *Targeting the Computer: Government Support and International Competition* (Washington, D.C.: Brookings Institution, 1987), p. 38.

12. See Edwin Mansfield and others, "Social and Private Rates of Return from Industrial Investment," *Quarterly Journal of Economics* (May 1977), pp. 221-240.

is twice the private rate of return, is it so for a given project? Furthermore, when does the government stop--how much federal support for R&D is enough? As outlined in Chapter I and Appendix A, the federal government is currently funding an estimated $400 million to $500 million of semiconductor research. This level is roughly one-sixth of the semiconductor R&D being done in the entire economy, although it is more like one-fifth of the R&D being done by semiconductor producers--the rest being done by producers of semiconductor manufacturing equipment.

## "Downstream" Applications

There is little to suggest that the social benefits of future semiconductor R&D will be substantially less than those attributable to previous research. Technological advances since the early 1970s have made it possible to squeeze ever-larger numbers of circuits onto a single chip. This ability has had the effect of blurring the distinction between semiconductor components and systems. For example, the advanced microprocessor is virtually a tiny computer on a chip. As integrated circuit design shades into system design, innovation in semiconductor technology becomes directly intertwined with innovation and development in end-use industries. The future direction of semiconductor innovation with ever-smaller devices suggests that greater electronic capability will become available for more and more uses.

The semiconductor is probably an epochal invention; the future of manufacturing technology increasingly depends on semiconductor-based applications. From the conceptualization phase with computer-aided design, through the manufacturing phase with computer-integrated manufacturing processes, all aspects of production are premised on having integrated circuits that are more complex and powerful yet cheaper than exist today. Many of the dependencies are obvious: for example, without semiconductors there would be no robots. In other cases, the ties are less apparent: for instance, the increased use of "statistical" control of the manufacturing process depends entirely on the rapid absorption, transmission, and analysis of information on production lines. More rugged versions of the personal computer are being introduced on factory floors for controlling the manufacturing process. Semiconductors are at the heart of all this information technology.

Because the R&D performed in the semiconductor industry will spread to all other U.S. industries, federally funded semiconductor R&D can be viewed as a way of supporting R&D for industry as a whole. The benefits from semiconductor R&D will help other industries be more productive.13/ For example, semiconductors have allowed electronic components in manufacturing equipment to replace mechanical functions. These replacements typically have reduced the number of working parts and have increased the speed and reliability of the equipment, thus leading to measurable productivity gains. In addition, flexible manufacturing systems depend on electronic computers and other equipment that can be reprogrammed easily while maintaining precision. These systems typically operate faster and more reliably than the systems they replace, often producing outputs of higher quality. They also reduce the "down time" needed for making product or style changes, thus allowing quicker and less costly response to changing market conditions.

Although at some point these advances will slow down, few analysts believe that that will happen soon.14/ For example, the rate at which the costs of components declined began to accelerate in the late 1970s and has continued through the 1980s.15/ But the dwindling number of merchant producers threatens to hasten the decline of the rate of innovation in this industry. The merchants and niche producers have been faster to introduce new designs than have the captive producers, partly because of differences in motivations and market strategies. As noted in the previous chapter, the merchant sector has been especially hard hit by Japanese expansion and tendencies in the industry toward vertical integration. Sematech is explicitly intended to strengthen the merchant manufacturing technology base, thus strengthening the most innovative sector of the industry.

---

13. For discussions of upstream and downstream R&D, see Congressional Budget Office, *Federal Support for R&D and Innovation*, pp. 37-47. See also Fumio Kodama, "Technological Diversification of Japanese Industry," *Science* (July 18, 1986), pp. 291-296.

14. Richard Levin, "R&D Productivity in the Semiconductor Industry: Is a Slowdown Imminent," in Herbert Fusfeld and Richard Langlois, eds., *Understanding R&D Productivity* (New York: Pergamon Press, 1982), pp. 37-54.

15. See Flamm, *Targeting the Computer*, pp. 21-32.

## Development of the Science Infrastructure

The manufacture of high-technology products such as semiconductors creates opportunities for the advancement of scientific knowledge. It provides scientists and engineers with new problems derived from the application of previous knowledge to practical situations. This process of "learning by doing" builds up a productive asset, human capital. Just as the products of semiconductor research can spread to other industries, the knowledge and experience gained by the scientists and engineers conducting the research can also be diffused elsewhere in the economy.

As scientists and engineers change projects and work in new areas, they bring with them the experiences of past learning, be it through formal education or practical training. But, as in other areas of research, no firm has as much incentive as does society to provide scientists and engineers with additional, post-formal education. Because of the propensity of firms to underinvest in the creation of human capital, industries where such growth occurs naturally are said to be worthy of note, and federally funded research that helps create that human capital can have important societal benefits.

There is a precedent for the role of high-technology industries as institutional repositories of the stock of human capital. The Bell Laboratories were an attempt by the Congress to use the regulatory process to build the industrial stock of human capital. The American Telephone and Telegraph (AT&T) company was guaranteed a rate of return on every dollar invested in Bell Laboratories. Consequently, the Bell Laboratories were built up for decades as the premier U.S. industrial laboratory and a major source of innovation for the economy. The breakup of AT&T ended that federal effort to build and preserve the industrial science base without providing a replacement.

## CONCLUSIONS

The above measures of federal interest are hard to quantify or to put into practice. Most industries make some unique contribution to the nation, and no measure allows analysts to rank the value of each contribution. This lack of a precise measure, however, does not obscure the existing good reason to believe that the market, left to its own devices, will fail to allocate the socially appropriate level of resources to many activities within the U.S. semiconductor industry.

This said, there remains a further set of questions concerning the cost of obtaining the benefits of competitiveness in semiconductor manufacturing.

Support for Sematech will cost the federal government roughly $100 million per year. But the U.S. semiconductor industry is returning to profitability, and there are many competing demands on the federal budget. Consequently, one must ask whether the public benefits of this industry are so great as to be worth the resulting increase in the federal deficit. Again, no readily available measure exists for comparing the benefits of reducing the deficit with the benefits of funding Sematech. However, the U.S. semiconductor industry may provide as good a case as can be made that the public benefits and spillovers resulting from the development of one industry justify federal financial support.

76-700 0 - 87 - 3

CHAPTER IV

# EVALUATION OF THE SEMATECH PROPOSAL

Over the course of the last two years, support for an industrywide consortium to improve U.S. semiconductor manufacturing technology has grown. This idea was promoted both by the Defense Science Board (DSB) and by a task force of Semiconductor Industry Association (SIA) members.1/ The industry is in the process of forming such a consortium, called Sematech, and has asked the federal government to participate and match funds provided by private members. The Congress must now decide whether to join the consortium and on what terms. This chapter describes the proposed consortium and examines the benefits and risks of the Sematech proposal.

## PLANS FOR SEMATECH

Sematech would be a six-year, $1.5 billion effort carried out in three phases.2/ As now envisioned, the intent of the consortium is to improve U.S. manufacturing technology in the areas of equipment, materials, and process. A planned production line would prove and integrate the technology, but actual full-scale manufacturing would be left to individual companies.

1. See Department of Defense, Defense Science Board, *Report of the Defense Science Board Task Force on Defense Semiconductor Dependency* (February 1987), p. 84. This report also made a series of subsidiary recommendations including establishing eight university centers for excellence in semiconductor science, doubling Department of Defense semiconductor R&D by refocusing current research efforts, increasing Department of Defense funding of semiconductor industry discretionary R&D, and forming a semiconductor advisory group. Depending on their configuration, several of these options may not cost the government substantial additional funds and so have not been analyzed here.

2. Sematech itself may go on longer, but current plans call for federal funding for six years only.

The proposed budget for Sematech would require commitments of roughly $250 million a year for the next six years (see Table 2). Funding would come from three sources: member firms, the federal government, and the state and local governments representing the site selected for the Sematech facility. Private membership is limited to U.S. capital-affiliated semiconductor companies and suppliers of semiconductor manufacturing equipment (SME), who can join through their trade association. Annual dues for semiconductor firms are 1 percent of semiconductor sales, whether to a market or to other divisions of the same company, with the proviso that no more than 15 percent of total funding can come from any one private source. This cap is designed to ensure that no one company can dominate the consortium.

The federal government's contribution to Sematech would be annual outlays of $100 million for six years, starting in fiscal year 1988. Additional funding is expected from the state and local governments in whose jurisdiction Sematech is located. Proposals from groups interested in providing a site for the Sematech plant are now being considered by Sematech's site-selection committee. A group of engineering schools in New York State, for example, has

TABLE 2. PROPOSED BUDGET FOR SEMATECH
(By fiscal year, in millions of dollars)

| | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 |
|---|---|---|---|---|---|---|
| Labor Costs | 23.1 | 50.0 | 60.7 | 67.2 | 71.0 | 74.6 |
| Operating Expenses | 18.0 | 33.8 | 41.1 | 45.2 | 46.6 | 46.9 |
| Contracts | 34.4 | 39.3 | 42.8 | 49.5 | 50.8 | 51.4 |
| Capital Expenses | 112.4 | 59.4 | 69.3 | 76.7 | 72.2 | 71.9 |
| Facility Acquisition | 40.0 | 44.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Facility Upgrade | 16.6 | 9.1 | 9.1 | 9.1 | 9.1 | 9.1 |
| Total | 244.4 | 235.8 | 223.0 | 247.7 | 249.7 | 253.9 |

SOURCE: Semiconductor Research Corporation, Research Triangle Park, North Carolina.

already offered Sematech a complex of facilities and an additional $40 million in incentives. In August 1987, the committee narrowed the list of possible sites from 13 to 6. Sematech will probably receive its state and local funding as soon as a site has been announced.

Sematech has three missions.3/ The first is to conduct research on advanced semiconductor manufacturing techniques. This R&D effort will be directed by the Semiconductor Research Corporation (SRC), an existing semiconductor R&D cooperative associated with the SIA, and will examine all phases of semiconductor manufacturing, such as lithography and etching. SRC will coordinate this R&D with other members of the semiconductor community, including consortium members, suppliers of semiconductor manufacturing equipment, universities, and federal agencies.

The second mission is to test and demonstrate the resulting techniques on a production line. The production line would run full time (seven days a week, 24 hours a day) and integrate all the manufacturing systems developed in the first component. Third, Sematech would develop processes to adapt these proven techniques so that they can be applied to the manufacturing of a wide variety of microelectronic products. The research for all these steps will be performed both by Sematech staff and by other organizations working under contract.

The six-year program calls for three concurrent phases corresponding to three different levels of density of integrated circuits. The near-term focus is on improving current commercial manufacturing practices rather than bringing entirely new materials or technology to the industry. Thus Sematech will concentrate on silicon rather than exotic materials, and on optical lithography rather than X-ray lithography. In later phases, however, new technologies may be needed. Phase 1, which would run from the last half of 1987 through the first half of 1990, focuses on the development of manufacturing technology for integrated circuits with minimum

3. This discussion is taken from a presentation on Sematech by Larry Sumney, President of the Semiconductor Research Corporation, to the Workshop on DOE National Laboratories and the Semiconductor Industry: Continuing the Joint Planning, at Sandia National Laboratory, Albuquerque, New Mexico, May 26, 1987.

feature size (commonly called geometries) of 0.8 micron.4/ (A micron is one-millionth of a meter.) Phase 2, which would begin shortly after Phase 1 and run through 1990, concentrates on geometries of 0.5 micron. Phase 3, which would begin in 1988 and would run through the first half of 1994, is intended to develop manufacturing technology for geometries of 0.35 micron.5/

The companies that join Sematech do so in order to involve themselves in the forefront of research on manufacturing process, in the hope of incorporating this research into their own facilities. The technology developed by Sematech will go first to member firms. But as makers of semiconductor manufacturing equipment incorporate the results of this research into their products, the technology will eventually spread to all semiconductor manufacturing firms in the United States, then to firms abroad. The benefits to the member firms would be the head start on the use of the technology, not an absolute monopoly. Technology developed by Sematech would become available under license after a suitable period, with the proceeds being used to fund further research. Sematech planners propose that the federal government, like any other partner, be eligible for a royalty-free license of any resulting technology.

Plans for Sematech include a formal program to transfer the technology to its members. This program culminates with Sematech personnel providing on-site assistance to member firms in implementing the new technology. Long before this step, however, member firms would receive interim reports and technical communications from Sematech staff. The consortium also plans to provide suppliers of semiconductor manufacturing equipment who win Sematech contracts with technical findings to incorporate into their products. A 500-person staff is anticipated, and supplying that number of people should not be a constraint. The industry consortium

4. Only leading-edge DRAMs have reached this level of minimum feature size, and these devices have not yet entered mass manufacture.

5. Sematech may choose in later phases to participate in the development of synchrotron-driven X-ray lithography. The Congress is now considering a proposal for the Departments of Energy and Defense to develop such technologies jointly.